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EVALUATION OF AN IMPROVED CONVECTION TRIGGERING MECHANISM IN THE NCAR COMMUNITY ATMOSPHERE MODEL CAM2 UNDER CAPT FRAMEWORK

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4.4   EVALUATIONOFANIMPROVEDCONVECTIONTRIGGERINGMECHANISMINTHENCAR COMMUNITYATMOSPHEREMODELCAM2UNDERCAPTFRAMEWORK

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1.INTRODUCTION

The problem that convection over land is overactive during warm -season daytime in the National Cen ter for Atmospheric Research (NCAR) Community Atmosphere Model CAM2 and its previous version (CCM3) has been found bothinitssingle -columnmodel(SCM)simulations (XieandZhang2000;Ghanetal.2000;Xieetal. 2002) and in its full general circulation   model (GCM) short -range weather forecasts (Phillips et al. 2003) and climate simulations (Dai and Trenberth2003). Thesestudiesshowedthatthis problem is closely related to the convection triggeringmechanismusedinitsdeepconvection scheme (Zhang and McFarlane 1995), which assumes that convection is triggered whenever there is positive convective available potential energy (CAPE). The positive CAPE triggering mechanism initiates model convection too often during the day because of the strong diurna   l variationsinthesurfaceisolationandtheinduced CAPE diurnal change over land in the warm season. To reduce the problem, Xie and Zhang (2000) introduced a dynamic constraint, i.e., a dynamic CAPE generation rate (DCAPE) determined by the large -scale advective tendenciesoftemperatureandmoisture,tocontrol theonsetofdeepconvection. Theyshowedthat positive DCAPE is closely associated with convection in observations and the dynamic constraint could largely reduce the effect of the strong diur nal variations in the surface fluxes on the initiation of convection.   Using the SCM version of CCM3, which has the same deep convection scheme as CAM2, Xie and Zhang

(2000) showed that considerable improvements can be obtained in the model simulation of precipitationandotherthermodynamicfieldswhen thedynamic constraint was applied to the model triggering function. However, the performance of theimproved convection triggering mechanism in thefullGCMhasnotbeentested.

Inthisstudy,wewillte   sttheimprovedconvection trigger mechanism in CAM2 under the U.S. Department of Energy's Climate Change Prediction Program (CCPP)   - Atmospheric Radiation   Measurement   Program   (ARM) Parameterization Testbed (CAPT) framework, which provides a flexible envir   onmentfor running climate models in Numerical Weather Prediction (NWP)mode. Incomparisonwithtestingphysical parameterizations in climate simulations, the CAPT strategy uses more available observations and high -frequency NWP analyses to evaluate model performance in short -range weather forecasts. This allows specific parameterization deficiencies to be identified before the compensation of multiple errors masks the deficiencies, as can occur in model climate simulation. Another advantage of the CAPT approachisitscapabilitytolinkmodeldeficiencies directly with atmospheric processes through case studies using data collected from major field programs(e.g.,ARM).

2. BRIEF DESCRIPTION OF THE MODEL AND THEIMPROVEDTRIGGERINGMECHANISM

The mod el used in this study is the NCAR CommunityAtmosphereModel(CAM2),whichisa

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global spectral model with T42 truncation (2.8^0 x 2.8^0, which is around 300km) in the horizontal and 26 levels in the vertical. Detailed information about CAM2 can be seen in Collins et al. (2003). The deep convection scheme used in CAM2 was proposed by Zhang and McFarlane (1995). It is based on the plume ensemble concept similar to Arakawa and Schubert (1974). This convection scheme assumes that convection occurs whenever th ere is a positive CAPE. Previous studies showed that this assumption could lead the model to produce excessive daytime precipitation over land during the warm season. To reduce this problem, Xie and Zhang (2000) introduced a dynamic CAPE generation rate (DCAPE) to control the onset of deep convection. DCAPE is defined as the change of CAPE solely due to the total large -scale advection over a time interval. They assumed that deep convection occurs only when the large -scale advection makes a positive contri bution to the existing positive CAPE. This large -scale dynamic constraint allows CAPE to accumulate from surface process before convection occurs and links model deep convection closely to the large -scale dynamical processes, such as large -scale upward mot ion and low -level moisture convergence. It is well known that these large -scale dynamical processes play an important role in destabilizing the atmospheric structure, initiating and maintaining deep cumulus convection. Xie (1998) showed a strong in -phase c orrelation between positive DCAPE and convective activities using data collected over both midlatitude land and tropical ocean.

3. EXPERIMENTS AND RESULTS

As part of the CAPT framework, the CAM2 model is initialized with the European Center for Medium -range Weather Forecast (ECMWF) reanalysis (ERA-40). A series of 36 -hour forecast runs is initiated every day at 00Z for 31 days starting from June 18, 1997 to July 18, 1997. This period is selected to cover the ARM summer 1997 Southern Great Plains (SGP) Intensive Operational Period (IOP), which is from 2330Z June 18, 1997, to 2330Z July 17, 1997. A composite of 12 -36 hour forecasts from the series of 36 -hour runs is analyzed. Selected important meteorological fields are discussed with a focus on the mod el-simulated precipitation field. Comparisons are made with available ARM and other observations, and with high -frequency NWP analyses at the ARM SGP site and other important climate

regions. In this extended abstract, however, only the simulated precipit ation, temperature, and moisture fields are summarized. More detailed discussions about the simulation of other fields, such as clouds, surface sensible and latent heat fluxes, and radiation fluxes, will be given in the upcoming American Meteorology Socie ty (AMS) meeting and a separate research paper. For convenience, we use CAM2O to represent the original model and CAM2M to represent the model with the modified triggering mechanism, and OBS to represent observations in the following discussions.

3.1 Com parison at ARM SGP site

Figure 1 shows the time series of surface precipitation rates for CAM2O, CAM2M, and the corresponding observations averaged over a grid cell centered at the model grid point (37.67N, 98.44W). Similar results are seen at other

Simulated and Observed Precipitation
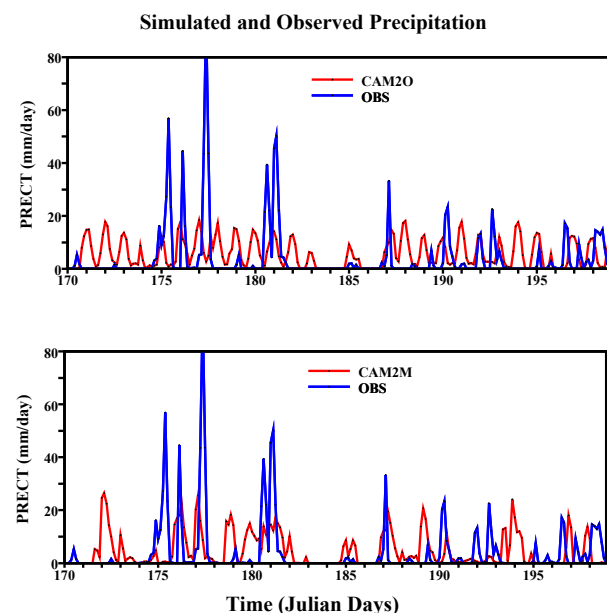
Figure 1. Time series of precipitation for CAM2O, CAM2M, and the observations at the ARM SGP site.

neighbor grid cells. The observations show several strong convective events during this period. It is seen that convection is triggered too often in CAM2O, which produces precipitation almost everyday during the daytime. This problem is noticeably reduced when the dynamic constraint is used to control the initiation of convection (CAM2M). Since CAPE can accumulate before convection occurs in CAM2M, rel atively stronger

precipitation events are produced by the improved scheme in comparison with CAM2O.

Even with the overall improvement, some spurious precipitation events, such as those on days 172 - 173 and day 194, are still seen in CAM2M. In addition, th e magnitude of the observed precipitation is still underestimated in CAM2M during strong convective periods that occurred on days 174 – 178 and days 180 -181. The underestimation is also seen in CAM2o. Note that the underestimation of the observed precipit ation events, which are mainly dominated by subgrid -scale convective processes, is not uncommon in climate models, which typically use horizontal resolutions that are larger than 200 km. The problem could be improved with increasing the model resolutions (Duffy et al. 2003). In addition, the performance of model convection scheme is largely dependent on the accuracy of the initial data and the model -produced large -scale dynamic fields, such as large -scale vertical motion and advective tendencies of winds, temperature, and moisture. A comparison between the large -scale vertical motion derived from the ERA -40 reanalysis and the ARM objective variational analysis shows that the ERA -40 reanalysis - derived vertical motion is much weaker than that derived from t he objective analysis during these strong precipitation periods (not shown). This may also cause the weaker precipitation produced by the model.

Differences between the simulated temperature and the ERA -40 reanalysis at the selected model grid point are shown in Fig. 2. The original model (CAM2O) shows a warm bias in almost the entire troposphere, especially in the levels between 665 mb and 215 mb, when compared to the ERA -40 reanalysis. The warm bias exhibits a diurnal variation, indicating that it ma y be related with the model-produced overactive convection that releases excessive convective heating in the mid - and upper troposphere. The warm bias is largely reduced in CAM2M. The improvement is mainly located between 665 mb and 215 mb. Below 665 mb, both CAM2O and CAM2M display a very similar error pattern with a similar magnitude of the model bias. This may suggest that the error in the lower troposphere is related to problems associated with the model boundary layer processes.

Figure 3 is the same as Fig. 2 except for the moisture simulation. Both CAM2O and CAM2M

show dry bias in the lower troposphere over the whole period except for day 185, where both models produce significant moist bias due to the failure to capture the abrupt reduction of moisture shown in the ERA -40 reanalysis during that time. However, the magnitude of the dry bias in CAM2M is much smaller than that in CAM2O because convection is less active in CAM2M than the original model. This results in less moisture consumed by co nvection in CAM2M.
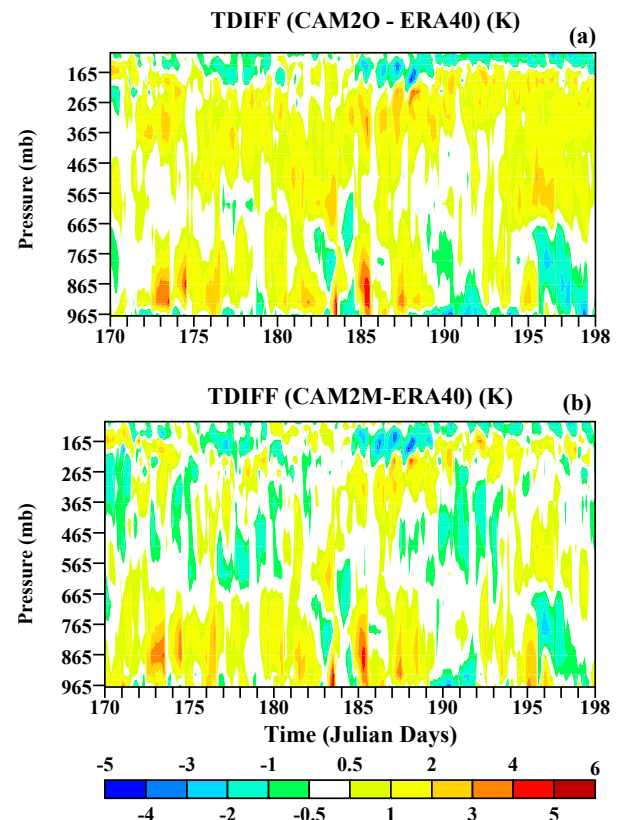
Figure 2. Differences between the simulated temperature and the ERA -40 reanalysis. (a) CAM2O; and (b) CAM2M.

In comparison with the ARM observations and the ERA-40 reanalysis at the ARM SGP site, overall improvements can be seen in other important atmospheric fields, such as clouds, surface sensible and latent heat fluxes, and radiation fluxes, when the new triggering mechanism is used (not shown in this abstract). These results are similar to those shown in the SCM tests (Xie and Zhang 2000; Ghan et al. 2000; Xie et al. 2002). Note that improvements made in SCM tests are not guaranteed to be transferable to its parent GCM due to the limitation of the SCM framework, such as the lack of the internal

feedbackbetweenthemodeld ynamicalprocesses andphysicalprocesses. Theencouragingresults shown in this study indicate that the improved schemeproposedbyXieandZhang(2000)based on the SCM framework has passed another importanttest,i.e.,thetestinafullGCM.

QDIFF (CAM2O-ERA40)(g/kg) **(a)**

QDIFF (CAM2M-ERA40) (g/kg) **(b)**
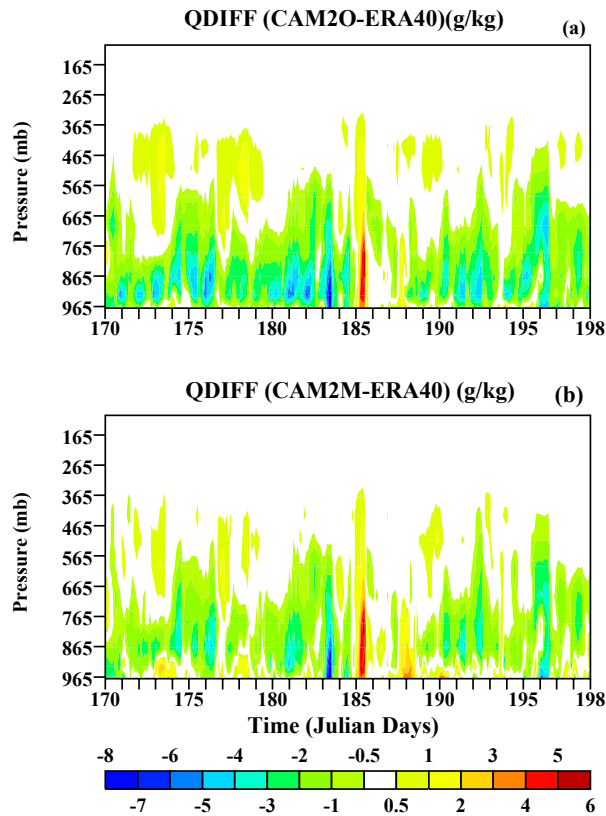
Figure 3. Differences between the simulated moistureandtheERA -40reanalysis.(a)CAM2O; and(b)CAM2M.

3.2ComparisonbeyondtheARMSGPsite

Toexaminetheimpactoftheimprovedconvective triggeronsimulationsinregionsbeyondtheARM SGP site, Figure 4 displays the geographical distribution of precipitation over the region that coversthecontinentalUnitedStates. Themodel dataaretheensemblemeanprecipitationof0 -24h forecasts over the 31 days as described earlier. The observations ar e taken from Global Precipitation Climatology Project (GPCP) daily precipitationdata(Huffmanetal.2001)andthese data are averaged over the same period as that covered by the model data. The GPCP dataset hasaspatialresolutionof1 ^{0}.Duringthesu mmer period, the heaviest precipitation is seen in the southeastandalongtheGulfCoastintheGPCP

data. Anotherrelativelylargerainfallregioninthe observations is located southwest of the Great Lakes along the Mississippi -Wisconsin Rivers. Slight precipitation is seen between these two major precipitation areas from the southwestern U.S. stretching northeastward into the Northeast Coast. Overall, the observed spatial pattern of precipitation appears to be more realistically simulated in CAM2M, al though it underestimates thesoutheastprecipitationandshiftsthecenterof the precipitation along the Mississippi -Wisconsin rivers slightly father north compared to the observations. The original model overestimates the observed precipitation in most parts of the countrywhiletheexcessiveprecipitationisclearly reducedinCAM2M. Itisinterestingtonotethat both CAM2O and CAM2M show a precipitation maximumlocatedintheeastoftheRockies,which is not shown in the observations. This phenomenon is also present in the summer precipitation field for the mean of all CMIP (Coupled Model Intercomparison Project) models (Coquard et al. 2003). The physical reasons for themodelsystematicerrorarenotwellunderstood and are subject to additional study. However, results from this study indicate that this model systematicerrorcanbedetectedintheearlystage of model integration. This has very important implications for understanding what model deficiencies cause the systematic error since it allows us to perform a more in -depth analysis during a short time period where more observations are available and different model errors from various processes have not compensatedforthesystematicerror.

Inadditiontotheseimprovementsovermidlatit ude lands, more encouraging improvements are also seen in other areas, including the tropical and subtropical regions. As shown in Fig. 5, which gives the global distribution of precipitation for CAM2O, CAM2M, and the observations, CMA2M reproducesdramat icallywelltheprincipalfeatures of the observed precipitation distribution, particularly in the Tropical Pacific and India Oceansandin northAfrica. Incontrast,CAM2O generallyoverestimatestheobservedprecipitation globallyintheshort -rangewea therforecastswhile it underestimates the magnitude of the observed precipitationmaxima,suchasthoseintheeastern Pacific and in the northeastern boundary of the Bay of Bengal. These results indicate the improvedtriggeringmechanismdevelopedbyXie and Zhang (2000) based on the midlatitude observationsisalsosuitableforuseglobentallyand,

in fact, it makes even larger improvement over
oceansthanlands.
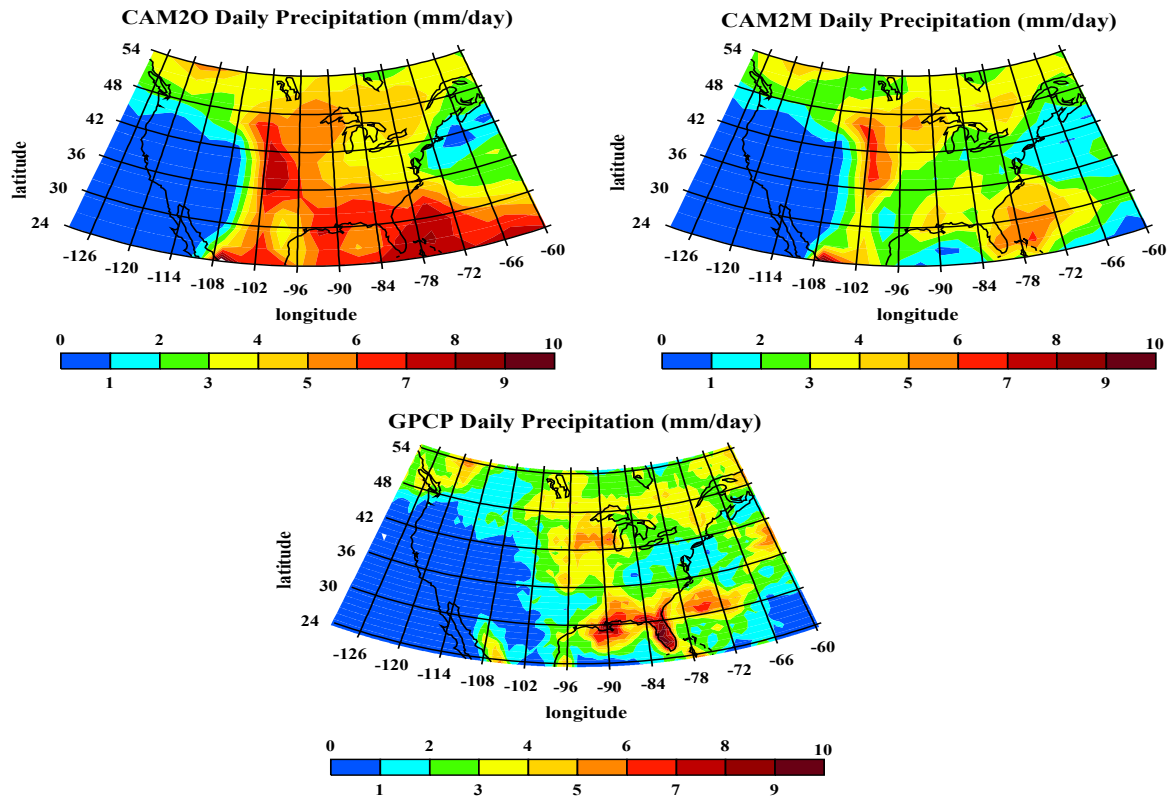
Figure4. Geographicaldistributionof31   -dayensemblemeanprec   ipitationoverthecontinentalUnited
StatesforCAM2O,CAM2M,andtheGPCPdata.
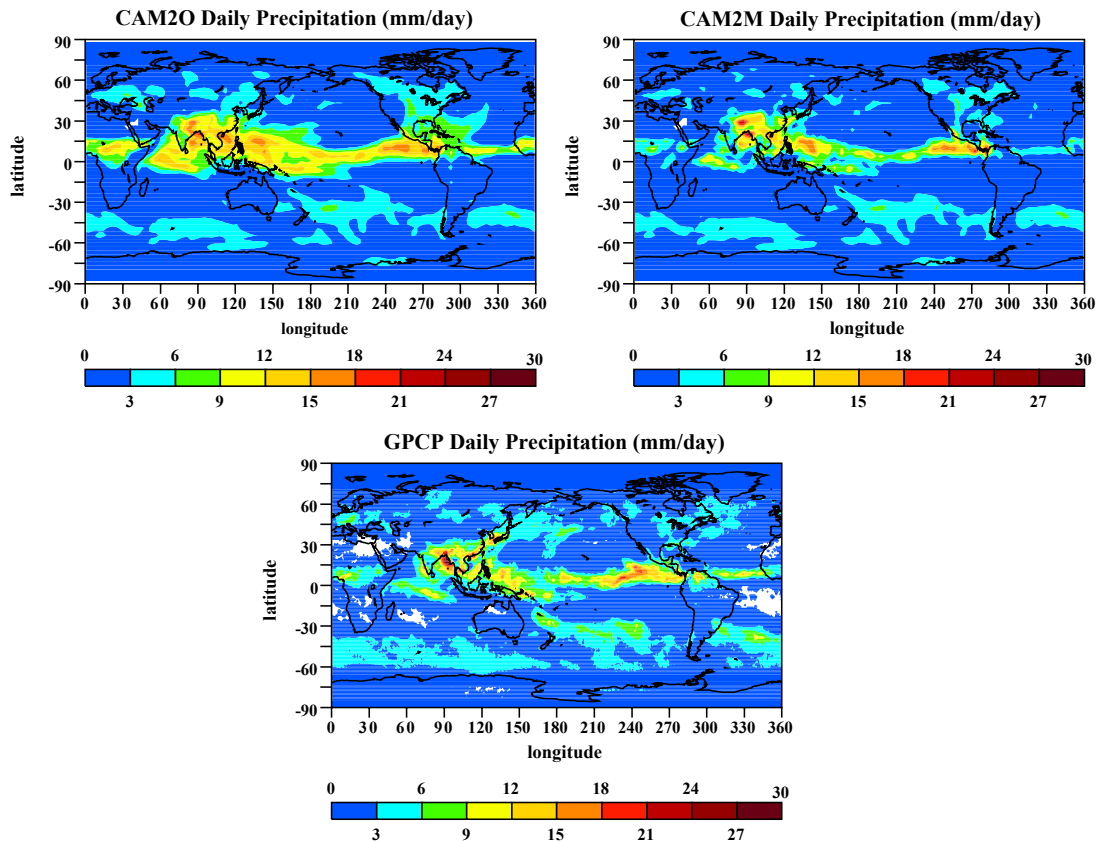
Figure 5. Global distribution of 31 -day ensemble mean precipitation for CAM2O, CAM2M, and the GPCPdata.

4.CONCLUSIONS

In this study, we have evaluated the improved convective triggering mechanism proposed by Xie and Zhang (2000) in CAM2 under the CAPT framework, in which the climate model is run in NWP mode. The new triggering mechanism introduces a dynamic constraint on t he initiation of convection. It has been shown that the model with the new triggering mechanism can effectively reduce the problem associated with the overactive convection in the original model. This results in a more realistic precipitation field simul ated by the model. Improved results are seen over both land and ocean when compared to the available observations at the ARM SGP site, in the continental United States, and around the global. Similar improvements are also present in other important meteo rological fields, such as temperature, moisture, and clouds (not shown). This study represents an important and efficient step to transfer improved parameterizations made from SCM tests to 3 -dimensional climate models

before they can be used to improve c limate simulations. Evaluation of the new triggering mechanism in climate simulation is being pursued in a separate study.

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